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Starting-Up the Ernest Henry Underground Mine – Thermal and Occupational Hygiene Challenges

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ABSTRACT

The Ernest Henry Mine is a copper-gold open pit operation situated in northwest Queensland, Australia. It is owned and operated by Xstrata Copper, with a current throughput of 11 Mtpa, however, open pit operations are scheduled to cease in mid 2011. The deposit dips approximately 45° and extends for at least another 400 m vertically below the final 530 m deep pit design.

Construction and development of a sublevel caving (SLC) operation beneath the open pit was approved in December 2009. The feasibility design requires 39 km of development to be completed prior to production, which will commence in the fourth quarter of 2011. Initial ore production will be trucked and will increase to 3 Mtpa by the end of 2012, after which a hoisting shaft will be used. Ore production will then increase to 5 Mtpa in 2013 and ultimately to 6 Mtpa in 2016.

Two 3000 kilo watt of refrigeration (kW(R)) modular refrigeration plants will be installed, as well as two 1600 kW mixed-flow fans capable of a combined flow rate of 780 m^3/s at a total pressure loss across the mine of 2000 Pa. The main fans will be installed underground and will exhaust into the base of the pit.

The following challenges were faced in the development of the ventilation and refrigeration network:

- a relatively steep geothermal gradient,
- tropical ambient conditions,
- working under a wide pit shell, and
- a large underground trucking fleet prior to shaft commissioning.

A considerable number of ventilation studies were conducted with later studies extensively using Ventsim Visual™ mine ventilation software to complete the design process of the ventilation and refrigeration networks, including the comparison of several alternative designs.

The paper focuses on design challenges prior to the commissioning of the hoisting shaft, and discusses resistance optimisation and occupational hygiene-related design parameters, such as heat and diesel emissions, production level ventilation, main fan selection and location, and refrigeration requirements.

INTRODUCTION

The Ernest Henry deposit is located 38 km northeast of Cloncurry in the Eastern Fold Belt of the Mt Isa Inlier of NW Queensland. The operating company is Ernest Henry Mining Pty Ltd (EHM), which is 100 per cent owned by Xstrata Copper.

The ore zone is pipe-like and dips at approximately 45° to the south and in general is as thick as it is wide. The open pit has been in operation since late 1996 and is scheduled for completion in August 2011. The pit will eventually be approximately 550 m deep with a surface area of 140 ha and measuring 1.3 km × 1.5 km.

The underground mine targets the orebody down dip of the final pit shape. Minor ore tonnages remain contained in the sides of the pit where the orebody is larger than the lower excavation, with the majority of the ore reserves in a 425 vertical metre extension (670 m down dip). The mining shape on each level is relatively square with plan dimensions of approximately 220 m thick by 220 m wide in the upper section of the orebody. This remains relatively uniform throughout the orebody but the width does narrow at the bottom of the mine to 150 m wide.

The mine will produce a total of 72 million tonnes of ore over a 14 year period. Production will begin with trucking of initial stoping ore in the second half of 2011 (H2 2011) and ramping up to a rate of 3.0 Mtpa by late 2012. The shaft will be commissioned in H1 2013 with production planned

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to increase to 5.0 Mtpa by H1 2013 and to the maximum of 6.0 Mtpa in 2016, when the cave has been fully established. This maximum rate will be maintained until the mine closure which is expected in Q4 2024.

During the establishment years of an underground mine, capital development occurs at a significant rate. In order to maximise the net present value of the project, generation of revenue needs to start early in the project through production, prior to the commissioning on the hoisting shaft. This results in high early demand being placed on the ventilation network, which is typical of cave mine development where ventilation requirements are often greater than the production requirements. This early demand disappears with the commissioning of the hoisting shaft and the maximum ventilating capacity will not be required again for the remainder of the mine life. This is however available for a future development phase for a deeper mining block.

This paper details the ventilation and refrigeration requirements for the underground mining of the Ernest Henry mine orebody. With this option the bottom of the mining activities will be on 1200 mRL and development of other infrastructure down to 1100 mRL.

DESIGN CRITERIA

Ventilating air is used underground to dilute harmful contaminants such as dusts, gasses and fumes to safe levels. The main sources of these contaminants are production operations, diesels exhausts, exothermic chemical reactions, and fires.

Ventilating air also contains a certain amount of cooling power and is therefore also used to cool down men and machinery. As heat is added to the ventilating air the cooling power is decreased and eventually the ventilating air may become a heat source. Once this happens the air has to be cooled down by means of refrigeration plants and cooling installations. The biggest heat sources in underground mines are auto-compression, heat from rock, water, and machinery, with lesser amounts from lighting, men, explosives, compressed air mains and electric cables, oxidation of minerals and timber, and rock movement.

The specific requirements to achieve a safe and well ventilated underground environment are covered in the following criteria.

Queensland statutory requirements

The design of ventilation and refrigeration networks in Queensland is governed by the 'Mining and Quarrying Safety and Health Regulations 2001' (Queensland Mining and Quarrying Safety and Health Regulations, 2001) (referred to as 'Regulations') and the 'Mining and Quarrying Safety and Health Act 1999' (Queensland Mining and Quarrying Safety and Health Act, 1999) (referred to as 'the Act'). The following sections are most relevant to the design process:

- Section 48 of the Act – responsibility to ensure the ventilating air in a place is 'of a sufficient volume, velocity and quality to achieve a healthy atmosphere';
- Schedule 5 of the Regulations – the general exposure limits for various atmospheric contaminants;
- Guidance note QCN 03 of the Act dated October 2008, Version 6 – 'healthy atmosphere for underground mines';
- Section 27 of the Act – managing risk;
- Section 28 of the Act – unacceptable levels of risk;
- Section 5 of the Regulations – the responsibility of the site senior executive to ensure the establishment of risk management practices;
- Section 9 of the Regulations – monitoring of risks;
- Section 133 of the Regulations – 'limiting exposure to hazards'; and
- Section 143 of the Regulations – managing the risk when the wet bulb temperature exceeds 27°C and stopping work when the wet bulb temperature exceeds 34°C.

Exposure limits

General contaminants

Xstrata North Queensland has adopted the *National Exposure Standards for Atmospheric Contaminants in the Occupational Environment* (National Occupational Health and Safety Commission, 1995) and adjusted for 12 hour shifts and even time rosters. The criteria are shown in Table 1.

Diesel particulate matter ventilation rates

Derrington (2008) includes a full discussion on the issue of diesel particulate matter (DPM) and the increasingly stringent limits being imposed on underground mines. DPM is currently becoming a key limiting factor in the volumes of ventilating air required in underground workplaces where diesel engines are working. Derrington's discussion includes the development of cleaner burning diesel engines and the anticipated future advancements that will reduce DPM in exhausts to the point where DPM may no longer be the key contaminant to be managed.

An initial value of 0.05 $m^3/s/kW$ of rated engine power was used as one of the parameters for determining the air volume requirements in the study.

TABLE 1

Twelve-hour time weighted average (TWA) values applicable to diesel exhaust contaminants.

Pollutant	Work schedule category	8 hour shift TWA	12 hour shift TWA
Carbon monoxide (CO)	2	30 ppm	15 ppm
Nitrogen dioxide (NO_2)	3	3 ppm	2.8 ppm
Nitric oxide (NO)	4	25 ppm	12.5 ppm
Sulphur dioxide (SO_2)	1B	2.5 ppm	1.25 ppm
Elemental carbon (EC)	N/A	100 $\mu g/m^3$	100 $\mu g/m^3$
Organic carbon (OC)	N/A	NA	NA
Other trace materials including metals, sulfates, minerals, nitrate, etc	N/A	NA	NA
Total carbon (TC) = EC + OC	N/A	160 $\mu g/m^3$	160 $\mu g/m^3$
Diesel particulate matter (DPM) = EC + OC + other trace materials	N/A	200 $\mu g/m^3$	200 $\mu g/m^3$

Working in heat

The Mount Isa heat stress management procedure, known as the working in heat (WIH) procedure, was implemented at the Ernest Henry Underground Mine. The WIH procedure is based on the thermal work limit (TWL), which is defined as: 'the metabolic rate that people can safely maintain, expressed in Watts per square metre (W/m²)'. This is a function of wind speed, the wet and dry bulb temperatures and radiant heat.

Three trigger levels of 115 W/m², 140 W/m², and 220 W/m² are applied to the TWL:

- no work is allowed below 115 W/m²,
- from 115 - 140 W/m² only work to rectify the thermal conditions in the working place is allowed,
- only acclimatised people are allowed to work where the TWL is between 115 and 220 W/m², and
- unrestricted work is allowed when the TWL is above 220 W/m².

If the TWL in a working place drops below 140 W/m², 'altered conditions' are said to exist; normal production activities can no longer be continued and the only work allowed is to rectify the thermal conditions in that working place.

The dynamic nature of mining invariably means that although a design wet bulb temperature of 28°C is used to ensure altered conditions are not encountered, there will be a spread of values about this value that usually follows a log-normal distribution. The accepted design compliance for EHM is 95 per cent, accepting that up to five per cent of the working places would be non-compliant during the worst ambient conditions. Refrigeration requirements are designed to cool intake air to meet this criterion.

Radiation exposure

As the ore mineralisation contains minor amounts of uranium (average of approximately 65 ppm), the potential for radon gas in the underground environment was considered. Radon daughter product in-growth is a possibility in poorly-ventilated places and this is usually associated with increased radiation dose levels. The single use of air per ore production workplace was adopted as a design criterion.

None of the radon measurements conducted to date was above normal background radiation levels, however, future monitoring will be part of the mine's operation.

PRIMARY AIRFLOW REQUIREMENTS

The primary and secondary airflow needs were determined in an interactive process using typical equipment fleets. The network modelling described below was used to finalise these plans.

Capital development

The primary airflow requirements initially cater for the mine development phase during which time the required airflow increases rapidly, peaking at 820 m³/s at the end of 2012, when the trucking phase is fully established. After the shaft is commissioned and the trucks are no longer required, additional diesel powered loading units (two each of T11 or R3200 sized) will commence on both transfer levels, and two additional production loaders will start on the production levels.

The required airflow for each stage has been built up from first principals based on the equipment advised by the underground mining contractor and the in-house production fleet selected by the feasibility team.

The primary airflow requirements for the development phase have been based on the total kW of diesel operated equipment in use. The development equipment fleet increases to a total of four jumbos with supporting equipment and the logic used to arrive at the ventilating quantity is shown in Table 2.

It is probable that all of the vehicles indicated in each row of Table 2 will be operating underground simultaneously at some point and therefore the maximum cumulative quantity has been used as the design basis. Figure 1 below indicates the total rated engine power distribution for the primary development which shows that the trucks account for almost 50 per cent of the total rated engine duty.

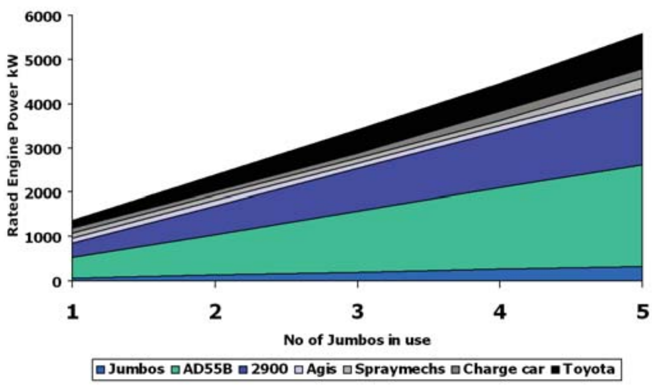

FIG 1 - Total rated engine power distribution for the capital development.

Production levels

The production phase is scheduled to require three levels in full production, however, the ventilation estimates have allowed for an additional level to ensure redundancy. The total orebody ventilation requirements are based on activity in six production levels and an additional footwall development level which is outlined in Figure 2.

Typical level development equipment includes a jumbo, R2900 sized loader and a charge car or shotcreting rig. Typical production level equipment includes a drill rig, one or more R2900 sized loaders and a charge car or shotcreting rig.

TABLE 2

Equipment ventilation requirements based on jumbo utilisation.

No of jumbos	Volume m³/s	AD55Bs	2900s	Agis	Spray mechs	Charge car	Toyota
1	69	0.9	1	1	1	1	2
2	121	1.9	2	1	1	1	4
3	173	2.8	3	1	1	1	6
4	226	3.8	4	1	1	2	7
5	284	4.7	5	1	2	2	9

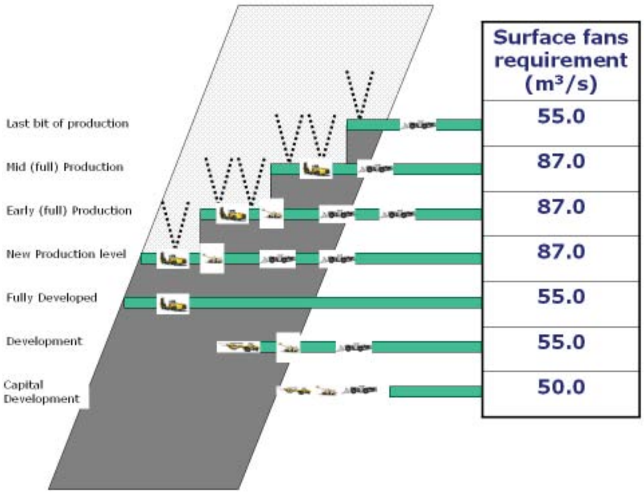

FIG 2 - Representation of the vehicles used on operational levels.

Composite airflow demand

The capital and operating requirements have been combined into a composite diagram which is included as Figure 3. Note the peak airflow requirements occurring at the end of 2012 with trucking at its maximum rate.

During the peak of the trucking phase, a slight shortfall in airway capacity is indicated (after leakage). The fan motors on the selected primary fans have some additional capacity and it is therefore envisaged that the fans will be capable of handling the July 2012 to January 2013 period despite this being over name-plate duty.

The ventilation network will need to be developed and installed in a timely manner to avoid temporary shortfalls in capacity such as the one indicated from February to June of 2010.

Main fan selection

The main fans will be installed in underground chambers with direct on line (DOL) starters. Mixed-flow type fans were selected due to their robustness and success from similar installations at Freeport (Duckworth *et al*, 2006). They are not as affected by erosion, corrosion, and build- up on the impeller and therefore retain their efficiency. While the performance of centrifugal fans is considered superior to other fan types, in an underground setting they require very large excavations and are less adaptable to an in-line configuration and were therefore disqualified as an option. Axial flow fans usually start out with high efficiency, however, this deteriorates with impeller wear and underground servicing of impellers is more difficult than on surface.

Secondary ventilation layout

Secondary ventilation during the mine development phase was not designed in detail, however, individual major changes to the ventilation circuits are being modelled in advance. Standard auxiliary ventilation fans and appropriately sized vent bag is being used with short term ventilation planning and modelling.

The conceptual design of the secondary ventilation network for the production phase is common to all production levels and is shown in Figure 4. On each side (western and eastern) a 90 kW fan will draw air from a fresh air system through a vent wall and charge a 1400 mm diameter rigid duct running along the length of the footwall drive. Airflow into production drives will be via T-pieces, 1400 - 1200 mm reducers, butterfly valves and finally 1200 mm vent duct.

Drawpoint air will return from the faces to the footwall drive and into the ore pass drives. From here drop board regulators will ensure the returned air, plus sufficient air to maintain a wind speed of 0.5 m/s into the footwall drive in parallel with the rigid ducting, will flow into the return airways and uncovered ore passes which will all be top exhausted.

The secondary system can ventilate up to four headings per level but cater for no more than two R2900 sized loaders. The butterfly valves will be capable of partially opening to ensure a higher airflow in the headings where loaders are working. All other headings require sufficient airflow to maintain 0.5 m/s wind speed. In order to achieve a total of 56 m^3/s at the working faces, a total of 87 m^3/s is consumed on each level (see Table 3).

VENTILATION NETWORK MODELLING

Circuit optimisation

Reviews of the prefeasibility study ventilation model were conducted by Derrington (2008) and Howes (2008). Together

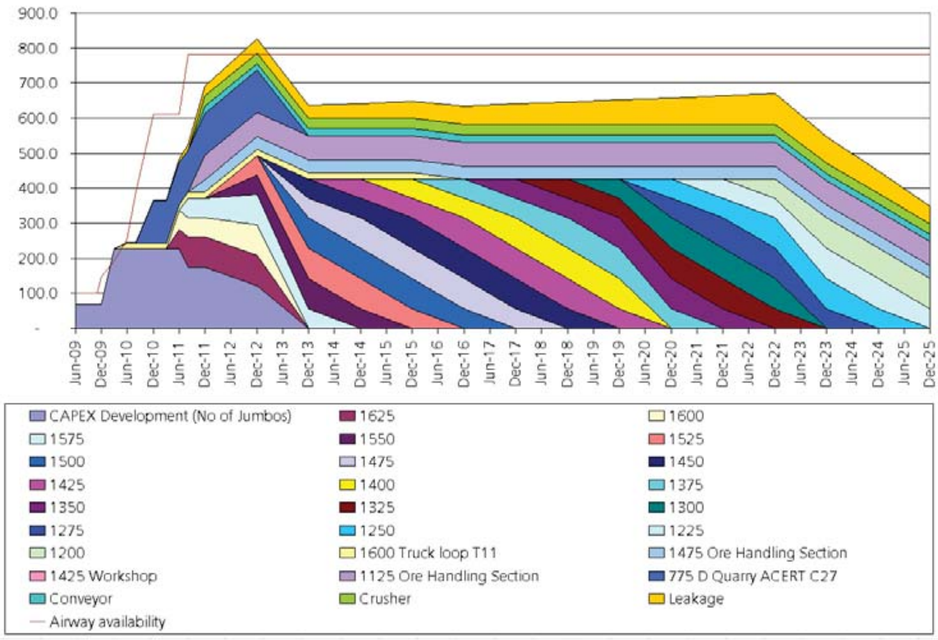

FIG 3 - Air volume requirement profile.

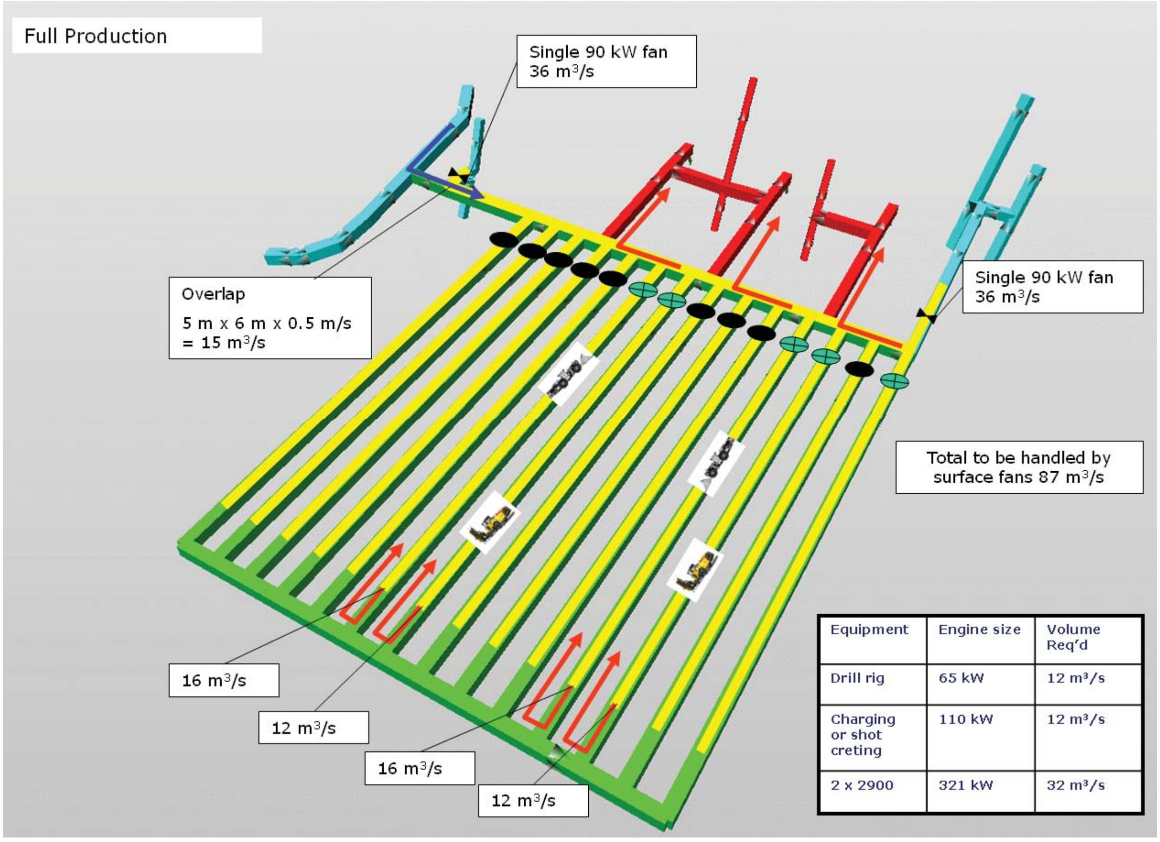

FIG 4 - Draw point level secondary ventilation layout.

TABLE 3

Ventilation requirements per draw point level.

Consideration	Volume of air required (m^3/s)
Volume required over the vehicles	56.0
Leakage through the ventilation bag	+13.0
Leakage across the closed butterfly valves based on 0.3 m^3/s per butterfly valve	+3.0
Subtotal	72
Two 45 kW fans installed in parallel in this system (see section 0) will supply	72.0
Volume of air required to flow past the fan installed in the access cross-cut to ensure a minimum velocity of 0.5 m/s to prevent recirculation of dusty air	+15.0
Total required to be handled for each of the three operating drawpoint levels	**87.0**

with up-dated mine design information, the Ventsim Classic model was up-dated and refined. At this point modelling began on a beta version of Ventsim Visual™, the outputs of which correlated well with the Howes (2008) review.

The design criteria listed in the previous section were used to reduce the mine resistance to an acceptable level by refining and optimising the primary airways. Differing criteria could be visually inspected by colour coded output models to determine which were the limiting factors to maintain a safe workplace. The airflow requirements were optimised based on DPM, and refrigeration requirements on TWL, with secondary inspection of wet bulb temperature. A number of mine designs, including the diesel trucking options, were modelled in this way. The co-author of this paper who is also the developer of the Ventsim Visual™ code, then reviewed the modelling in 2009 (Stewart, 2009).

Refrigeration

The initial refrigeration concept called for a single refrigeration plant location between the hoisting shaft and the escape way. From this central refrigeration plant the chilled and return water lines will transfer refrigeration to the bulk air coolers (BACs) on the escape way on the first switchback, and the hoisting shaft bulk air cooler. The escape way bulk air cooler would then supply cooling via the decline and the hoisting shaft BAC to the lower workings of the mine. This centrally placed refrigeration plant complex would allow a number of units to work together in the most efficient manner.

Optimisation of the trucking phase concluded that refrigeration on the decline side was only required for the two wet seasons prior to the shaft commissioning. During a value engineering phase, it was determined that the cost of piping and purchase of the plant represented a larger cost compared to having a smaller permanent plant close to the shaft and a second, temporary, self-contained refrigeration plant by the escape way.

The recommended final refrigeration configuration to achieve the 95 per cent compliance (see Working in Heat above) during the trucking phase is for a 5 MW(R) refrigeration plant to be sited near the portal location above the escape way feeding chilled water to an underground BAC located next to the decline.

For the long-term production phase including the overlap with the trucking phase a 5 MW(R) refrigeration plant is to be sited 250 m north of the hoisting shaft. This will feed a BAC sited at the shaft with chilled water transferred via a subsurface air duct into the shaft below the collar.

Subsequent to this, two modular plants were purchased and installed above the escape way, with chilled water piped to a heat exchanger near the underground BAC. Chilled water is then returned to the surface via a U-tube arrangement to minimise pumping costs. Any excess refrigeration capacity will be used to cool service water that will be used in deeper development headings. When the trucking phase is complete, the refrigeration plant and BACs will be relocated to the shaft.

NETWORK DESIGN

Network summary

The final ventilation network resulting from the design and optimisation process is shown in Figure 5. Light coloured airways indicate fresh intake air, dark coloured indicate main return air, and medium coloured indicate ventilating air that is travelling through workplaces and may not be completely fresh, but still useful to ventilate working places. All modelling used standard colours (only visible in colour versions of this paper) with blue of in-take, green for work places and red for return.

The ventilation network will have fresh air intakes into the underground mine from the decline, the escape way rise, an additional air rise, the hoisting shaft and a fresh air rise holing into the pit from the top production level ring drive. A system of return airways will direct return ventilation to two underground exhaust fans and into the bottom of the pit. Most ventilating raise bores are 3.5 m diameter.

Fresh air rises are located on both sides of the orebody. On the west of the orebody is the decline and a 5 m × 5 m long hole rise system feeding from the escape way and 1870 mRL rise. On the east of the orebody, the mid shaft drive supplies three parallel airways, two of which are fresh air rises and a third is a 1.8 m diameter escape way with reduced air velocity, ladders and rising lines. All operating levels draw fresh air from both of these systems.

Up to four headings will need to be ventilated on each production level. Air will be returned to the footwall drives and into the ore pass access drives from where it will enter the return air rise system in the centre of the footwall of the orebody. Two dedicated rises will pull air through drop board regulators in close proximity to the ore passes, and ore passes will also be top exhausted. The return air rises will extend from the bottom of the crusher and sumps through the transfer drives to the main exhaust system on 1625 mRL. When a stage of ore passes is no longer required, it will be converted to return air as well.

Once at the 1625 RL level, the ore passes and exhaust rises are connected via a manifold into two main exhaust drives of 6.5 m wide by 6.0 m high. Each drive will feed a 1.6 MW mixed flow fan located in a chamber approximately 11 m high by 10.5 m wide and 40 m long. These fans are designed to handle a combined duty of 790 m^3/s at a total pressure across the mine of 2200 Pa. From these fans, exhaust drives continue to the north at 1:6 incline before doubling back on themselves to break into the pit haul ramp on the footwall at approximately 1725 mRL. One of these drives will provide access to the pit.

Primary ventilation circuit development

The development of the primary ventilation circuit in parallel with main access and level development is essential to enable

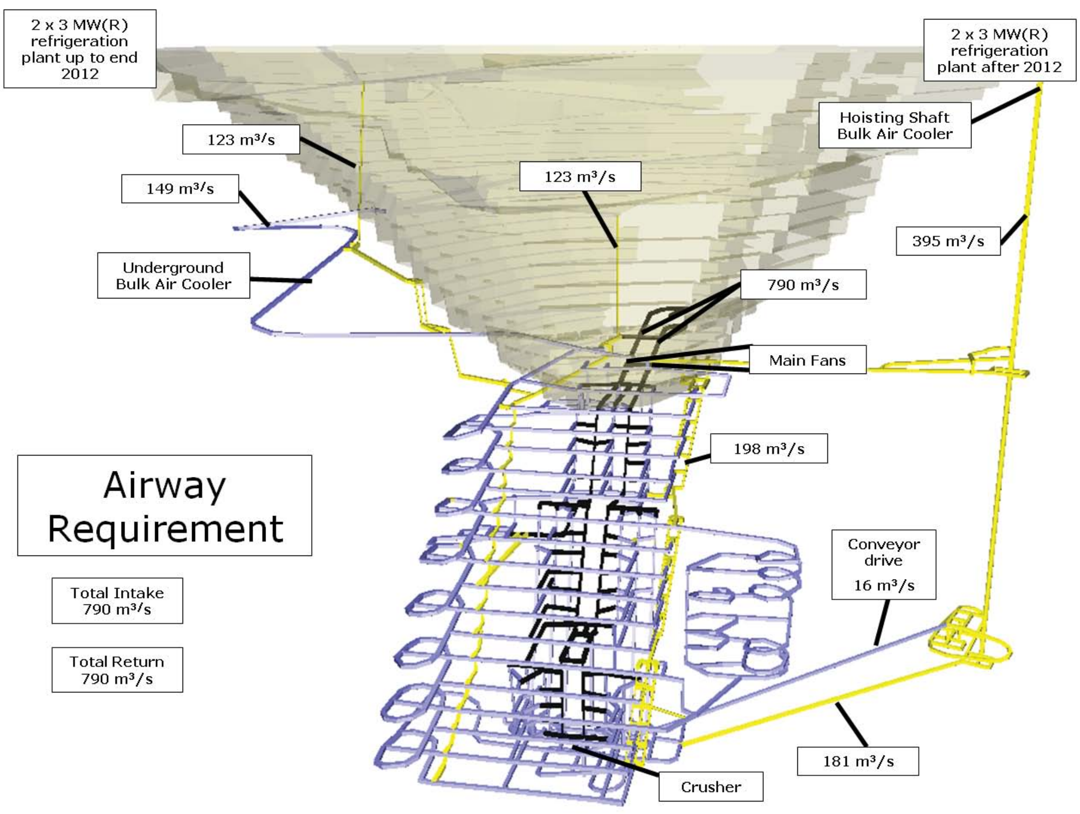

FIG 5 - Main ventilation and refrigeration design.

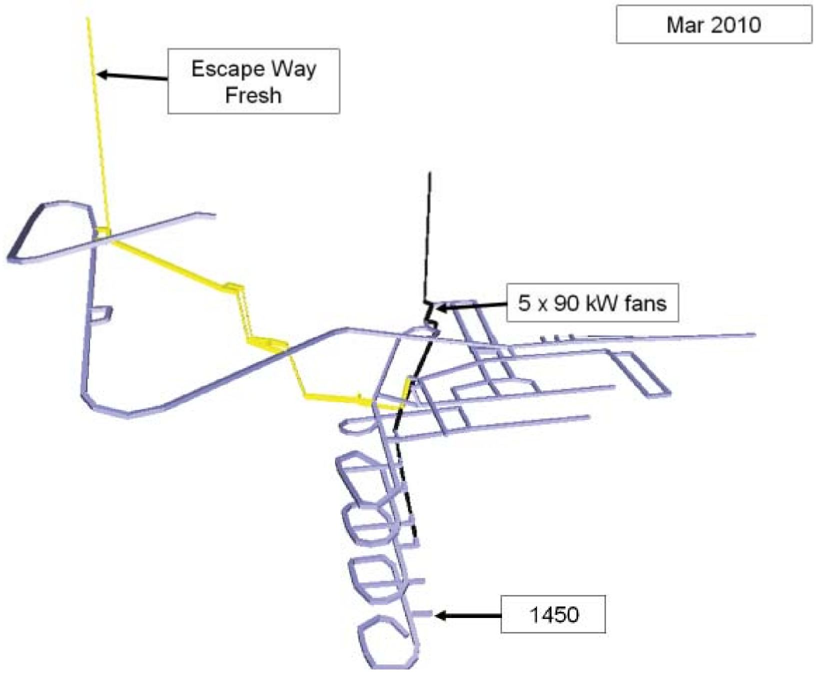

FIG 6 - Primary ventilation circuit in March 2010.

the mine development schedule to be achieved. In order to scope the duty required from the main fans and refrigeration plants, quarterly snapshots were taken from the development and production schedule and modelled using Ventsim Visual™. Both airflow and thermal modelling was conducted for each of these snapshots.

The following section summarises this process with a selection of snap shots at different times during the establishment of the underground mine. This includes a basic description of the development of the primary ventilation circuit aimed at minimising ventilation related issues. Light coloured airways indicate fresh intake air, dark colours indicate main return air, and medium colours indicate ventilating air that is travelling through workplaces and may not be completely fresh, but still useful to ventilate working places. All modelling used standard colours (only visible in colour versions of this paper) with blue for intake, green for work places and red for return.

Initial development

Figure 6 shows the primary ventilation circuit in March 2010 which is only a matter of months after the full shaft approval was given. The primary circuit consists of 5 × 90 kW fans returning all of the mine's ventilating air via the 1870 mRL fresh air rise back to the pit ramp. This arrangement has been measured at 193 m^3/s and is sufficient air for three jumbo drill rigs and their supporting vehicles. The fresh air rises from surface on the left (west) of the diagram are the surface escape

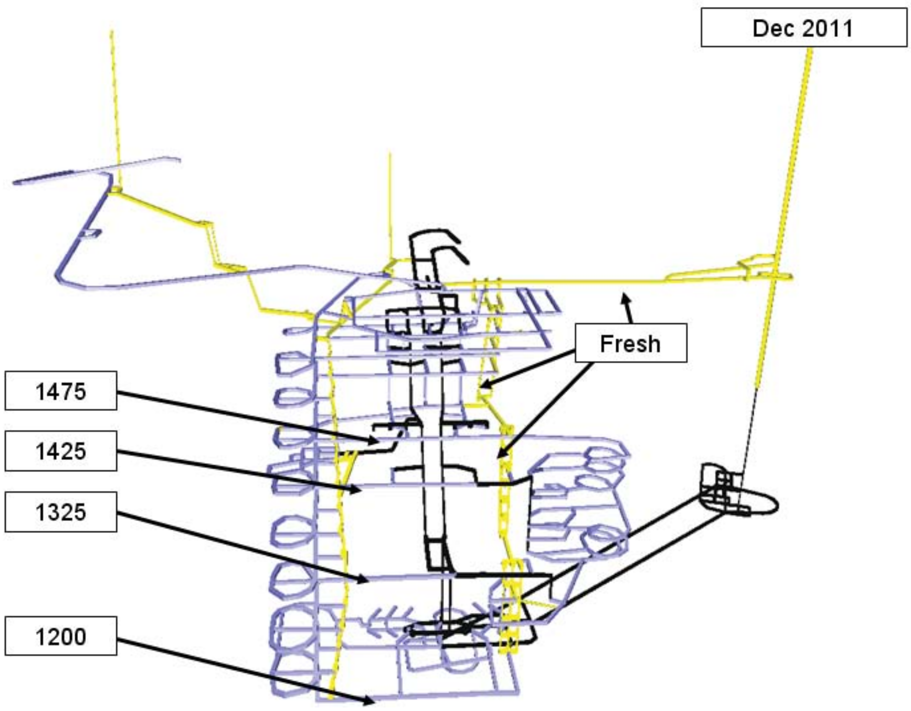

FIG 7 - Primary ventilation circuit in December 2011.

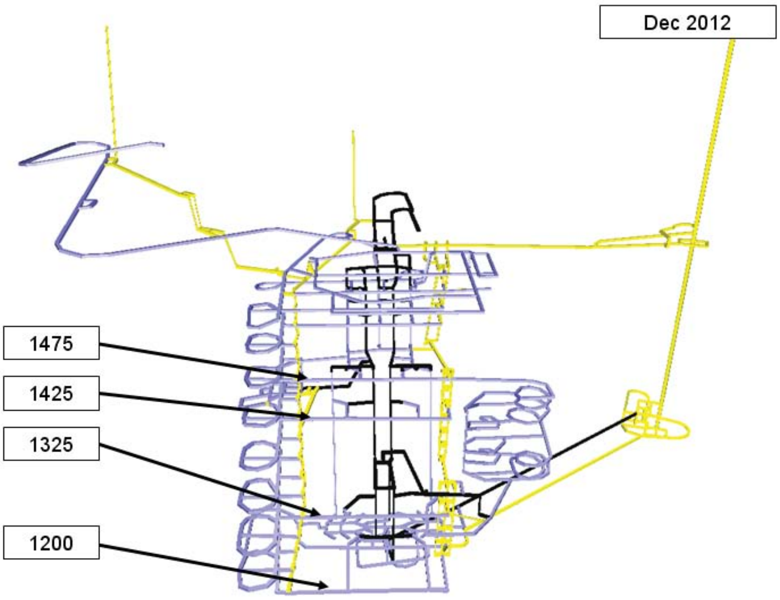

FIG 8 - Primary ventilation circuit in December 2012.

way and were used as return airways for the initial decline development.

A series of interconnecting long hole rises on the western side of the orebody near the decline serve two purposes. In the short-term these act as return airways, with their final function being to supply fresh air from the escape way and 1870 mRL rises into the production levels.

Primary development at the halfway mark

Figure 7 shows the primary ventilation circuit projected to the end of December 2011. At this stage the underground mine is roughly halfway developed and a total of 700 m^3/s is drawn through the circuit by the two main fans. Shaft sinking of the upper half of the hoisting shaft will be completed by October 2011 and sinking will be into the lower half. The mid-shaft drive will supply fresh air to the eastern FAR system and the temporary RAR arrangement will be removed.

Primary development almost completed and hoisting shaft about to be commissioned

Figure 8 shows the primary ventilation circuit at the end of December 2012. At this stage the hoisting shaft is almost commissioned and the volume of air drawn through the mine by the two main fans peaks at a total of 820 m^3/s. The refrigeration plant on the decline side will be decommissioned and a 5 MW(R) bulk air cooler will be installed and commissioned at the hoisting shaft to ensure acceptable summer conditions in the bottom access drive, conveyor belt and crusher. Note that the conveyor drive will be ventilated directly to return. All primary ventilation connections are now complete.

CONCLUSION

The initial years of the EHM mine requires a rapid build up of the volume of ventilating air up to the end of 2013 exceeding the remainder of the mine life. Utilising a combination of mine design, scheduling and ventilation software, a large number of scenarios was evaluated and optimised during the design process supplying a high degree of confidence in the final design. Rigorous evaluation of ventilation options reduces the likelihood of overdesigned infrastructure while ensuring good ventilation is available to achieve planned production.

Planning of the underground mine was peer reviewed at regular intervals. Following each peer review the ventilation and refrigeration plan was adjusted and reviewed by a number of different experts in the field of ventilation and refrigeration. Recommendations from these experts were compared and the best fit for Ernest Henry mine selected leading to a ventilation and refrigeration design described in this document.

This paper has concentrated on the final design being implemented at EHM. In parallel with this, a number of other options including trucking only were optimised in the same manner. The current power of on-site ventilation modelling software is a major breakthrough in a mine's ability to optimise, manage and predict the ventilation needs of their underground operations.

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